RESEARCH ARTICLE

Engineering Properties and Investigations of Emerging Modern Construction GGBS Based Geopolymer Concrete

Sandhya R.Jalgar[1], Anand M. Hunashyal[1], S.N.Mathad[2*], Raghavendra Jalgar[3]

[1]School of Civil Engineering, KLE Technological University, Hubballi, India
[2]Department of Engineering Physics, K.L.E Institute of Technology-580027, Karnataka, India.
[3]Water Resource Department (GoK), C/O Assistant Executive Engineer, KNNL,
MRBCC Sub Division No 12 Morab, Tq: Navalgund India.

ABSTRACT: For the complete replacement of Ordinary Portland Cement (OPC), the new technology of Geo-Polymer concrete (GPC) is a promising technique. An attempt is been made to study the optimum usage of Ground Granulated Blast Furnace Slag (GGBS) in concrete.An experimental study was conducted to obtain maximum strength by increasing the content of GGBS in concrete. GGBS based geo polymer concrete develops a flexural strength of 0.56MPa for 8M, 0.67MPa for 10M and 0.79MPa for 12M after 28 days of direct sunlight curing..The results showed the increase of compressive strength to a maximum by the inclusion of GGBS. After this optimum value, it was observed that the strength decreased. The optimum level of GGBS content was fixed to about 55-59% of the total binder content. In this study the geopolymer concrete is prepared by carrying out the usual concrete technology methods. Aggregates occupy the major volume, i.e. about 75-80% by mass in the normal concrete. In geopolymer concrete 78% of volume is occupied by aggregates. It was observed that with increase in molarity of NaOH, compressive strength of GGBS based geopolymer concrete increases. It is due to increase in alkalinity of mix, which increases the rate of geo-polymerization. It can also be observed that compressive strength increases with the age of concrete specimens. This is an attempt using only NaOH whereas Potassium hydroxide can also be taken in combination with NaOH to increase the strength. Sodium hydroxide is available in plenty and Potassium hydroxide is more alkaline than NaOH.

KEYWORDS: Alkalinity; binder; Geopolymerization; Admixtures; Aggregates

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INTRODUCTION

After lime and Ordinary Portland cement, Geo-polymer is considered as the new generation cement. Raijiwala [1] studied the influence of alkaline activators on the strength and durability properties of Geo polymer concrete. Sodium Hydroxide is available in plenty, and Potassium Hydroxide is more alkaline than NaOH. The results show that the compressive strength, Split Tensile Strength, and Flexural Strength of GPC increases over controlled concrete by 1.5, 1.45 and 1.6 times respectively. The combination of the above constituents (Na2SiO3, 50% NaOH and 50% KOH) at 800C has a positive impact on the strength and durability properties of geo polymer concrete. Padmakar et al., [2] using recycled aggregate with addition of admixture designed a design mix for rigid pavement. Padmakar et al and Vijaya et al., [3] analyzed the behavior of concrete by replacing the cement partially with fly ash, rice husk ash and silica fumes. Srinivas et al., [4] used the ceramic and granite waste as coarse aggregate and investigated the behavior of concrete. Padmakar et al., [5] gave an idea about the characteristic compressive strength of a geo-polymer concrete. George et al., [6] investigated the growth of nickel sulfate doped zinc tris-thiourea sulfate and photoluminescence study. Barhmaiah et al., [7] studied the peak hour analysis and effect of traffic composition on capacity of arterial roads. Mishra et al., [8] studied the effect of concentration of alkaline liquid and curing time on strength and water absorption of geo polymer concrete. Results indicated that there was an increase in compressive strength with increase in NaOH concentration. With increase in curing time, the strength was also increased. Compressive strength up to 46 MPa was obtained with curing

**Corresponding Author: physicssiddu@gmail.com*

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at 600C.

In this work, GGBS based geo-polymer is used as the binder to produce geopolymer concrete. The geopolymer glue which is obtained by the combination of source material and alkaline activator solution. In the normal concrete, the aggregates occupy the major volume, i.e. about 75-80% by admixtures mass. In this study the aggregates occupy 78% of volume in geopolymer concrete.

EXPERIMENTAL METHOD

GGBS: GGBS was purchased from godown near railway station in Hubballli, Karnataka, India whose specific gravity is 2.31.

Figure 1Ground Granulated Blast Furnace Slag

Coarse aggregates: Coarse aggregates were purchased from Swarna Constructions in Chalmatti whose specific gravity is 2.67 and fineness modulas is 2.1.

Fine aggregates: The fine aggregates were purchased from the Swarna Construction in Chalmatti whose specific gravity is 2.85 and fineness modulas is 3.27.

Alkaline solution: In this work, NaOH and Na2SiO3are alkaline solutions. Industrial grade Na pellets and the Na2SiO3gel were purchased from the local vendor in Hubballi.

Preparation of alkaline solution

Alkaline activator solution (AAS) plays an important role in geo-polymerization reaction of geopolymer concrete. AAS activates the Si and Al present in the binding or source material. In this preliminary study, 8 numbers of molarity solutions were prepared to make AAS of NaOH of 8M molarity. 8×40=320 gram of NaOH in flakes form was added to water to prepare one litre of solution, where40isthemolecularweightofNaOH. A lot of heat is generated when water is added to NaOH. To avoid any accident it should be handled carefully with help of hand gloves. To make AAS, Na2SiO3 was mixed with the solution of NaOH. Solution was stirred for 4 to 5 minutes for proper mixing of Na_2SiO_3 and NaOH. To increase the rate of geo-polymerization, sodium silicate is mixed in sodium hydroxide solution. In this research work AAS was prepared 1 hour before casting. Fig 2 depicts the whole methodology of the study.

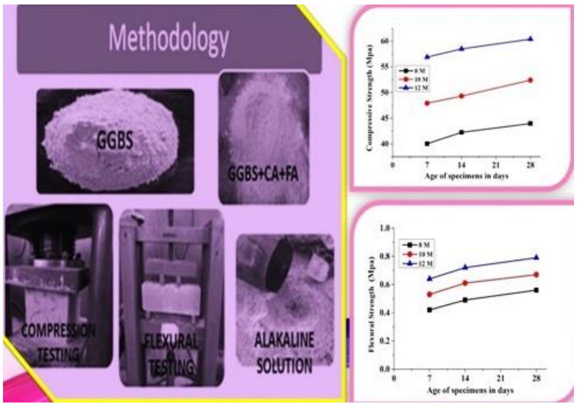

Figure 2 Schematic methodologies of the proposed work and results

Mix design details

Since GPC is a new constructional material which has developed in recent decades, there is no code provision for mix deign till now. Preliminary study is needed to be carried out for 7 days compressive strength of GPC samples to fix certain mixture parameters and to develop a mix proportioning of GPC.

In this study mainly two parameters vary in which one is alkaline solution to binder ratio and second is molarity of NaOH. Other parameter such as sodium silicate to sodium hydroxide ratio is kept constant and its value 2.5 has been taken.

Trial1 Mix Design:

There is no IS code or any code provision for GPC mixings. Hence trial mix design is adopted from past research papers.

Design steps are as follows:

The density of GPC is as summed as 2400 kg/m^3

Trial 2 Mix Design

- M1 =2400Kg/m^3
- M2=78%ofM1=1872Kg/m^3
- M3 =30%of M2=561.6 Kg/m^3
- M4 =M2-M3=1872-561.6 =1310.4Kg/m^3
- M5=M1-M2=2400-1872=528Kg/m^3
- r=0.40

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- M6=528/(1.40) = 377.143Kg/m^3
- M7= 150.857Kg/m^3
- Na2SiO3/NaOH=2.5
- M8 = M7/3.5=43.102 kg/m^3
- M9 =M7-M8 =107.755 Kg/m^3

Trial1 Mix Design

78% of M1 is taken as combined aggregates	Mass of combined aggregate varies from 70-80% in concrete as per IS code.
FA and CA are used in this test.	To find ratio of FA and CA, two trials are needed to be done.
The FA will be taken as 30%ofM2.	CA was taken as 70% of M2.
Alkaline liquid to source material ratio has come to 0.4 or 0.45.	

Some changes in mix proportions of trial 1 will be done. For mix design of trial 2, total aggregates were taken as 78% of total mass same as that taken intrial1. Fine aggregates and coarse aggregates will be taken same, but there will be a change in the alkaline liquid to source material ratio. In trial 2 we are going to take alkaline liquid to source material ratio as 0.45.

Mix design for trial 2

- M1 =2400 Kg/m^3
- M2=78% of 2400 =1872 Kg/m^3
- M3=30% of 1872 =561.6 Kg/m^3
- M4 =1872-561.6 =1310.4Kg/m^3
- M5=2400-1872=528Kg/m^3
- r=0.45
- M6 =528/(1.45) = 364.137Kg/m^3
- M7= 163.862Kg/m^3
- Na2SiO$_3$/NaOH=2.5
- M8= 163.862/3.5 =46.818kg/m^3
- M9= 163.862-46.818 =117.044 Kg/m^3

Notations used

M1=Unit weight of concrete
M2=Total mass of combined aggregates assumed
M3=Mass of fine aggregate (sand)
M4=Mass of coarse aggregates
M5=Mass of source material (GGBS) and alkaline liquid
M6=Mass of Source material (GGBS)
r = mass of Alkaline liquid to source material ratio.
M7=Mass of alkaline liquid
M8=Mass of NaOH solution
M9=Mass of Sodium silicate solution
FA=Fine aggregates
CA=Coarse aggregates

Results of the above design:

Table 1Trial mix design compression result

Trail Number	Compression test result (Mpa)
1	32.45
2	40.02

We had done two designs by varying the GGBS to alkaline solution ratio. We had obtained maximum compressive strength for the ratio 0.45.So by keeping the GGBS to alkaline solution ratio as 0.45; we have prepared the mix design for different molarities. The mix design for the different molarities is tabulated in the below table.

Mixing, casting and curing of specimen

The materials were weighed in surface dry condition to cast the samples. Then all the ingredients were dry mixed for 4-5 minutes by hand mixing as shown in Figure 3

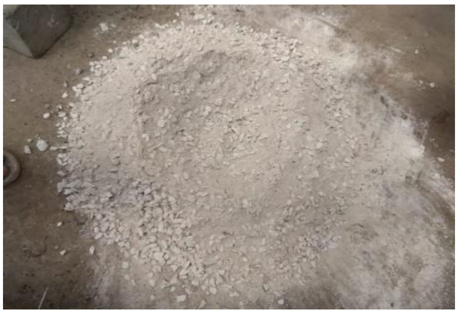

Figure 3 Dry mix of the GGBS, fine and coarse aggregates

Table 2 Mix design details for different molarities

Molarity	Materials						
	GGBS	Fine Aggregates	Coarse Aggregates	Sodium Hydroxide	Sodium Pellets	Water for NaOH preparation	Sodium Silicate
8 M	363.24	652.4	1220.3	46.8	11.3	35.5	117
10 M	363.24	652.4	1220.3	46.8	13.4	33.4	117
12 M	363.24	652.4	1220.3	46.8	15.2	31.6	117

After dry mixing of materials alkaline activator liquid was added to these dry ingredients, extra water was also added to increase the workability of mix and mixing was continued for 4-5 minutes. Fig 4 shows the addition of alkaline activator solution to the dry mix ingredients.

Fig 4: Addition of alkaline solution to the dry mix

The concrete was placed in standard cube of size 150×150×150 mm after the uniform mixing. Moulds were firstly cleaned from inside and oiled properly before filling the concrete for ease in moulding. Proper compaction was given to the specimens by putting them on mechanical vibrating table. After casting all samples were kept at room temperature for 24 hours before demoulding. After the demoulding of specimen, curing was done. For curing the samples were placed in air under sunlight for 7, 14 and 28 days. The moulds used for the casting were selected on IS specifications. The moulds specifications are listed in the below Table.

Table 3 Specimens casted details

Sr.No	Test	Mold Size	No of specimens Tested per molarity
1	Slump	Cone of top diameter 0.1m bottom diameter of 0.2m height of 0.3m	1
2	Compressive Strength	Cube of size 0.15m*0.15m*0.15m	9
3	Flexural Strength	Beam of size 0.5m*0.1m*0.1m	9

TEST ON FRESH GPC:

Slump cone test: When a concrete is easily mixed, placed, transported and compacted homogeneously i.e. without bleeding and segregation of concrete, then it is said to be workable. To determine the workability of fresh concrete the slump cone test was conducted.

Procedure for slump cone test

1. Mix all the ingredients properly and prepare the fresh GPC.
2. Fresh geopolymer concrete was placed in slump cone in three layers of equal volume and each layer was tampered 25 times with rounded end of tamping rod of 1.6cm diameter and 60cm long.
3. Then the cone was lifted vertically and the concrete was allowed to settle down.
4. The difference in the vertical distance of the concrete i.e. the original height to the settled height of the concrete is the slump value.

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TEST PERFORMED ON HARDENED GPC

Different tests i.e. compressive strength test and flexural strength test were conducted on the hardened concrete.

Compressive strength test

This test was carried out to determine the compressive strength of the concrete. This test was performed on cube of standard size 150mm×150mm×150mm as shown in Figure 5. The geopolymer concrete specimens were tested for compressive strength after 3, 7, and 28days of direct sun light curing. The compressive strength of any mix was taken as average of strength of two samples. All the specimens were tested using a compression testing machine.

Procedure for compression strength test

1. Firstly the specimen was placed in the machine for the compression test.
2. After proper placing of specimen the load was applied on the specimen gradually and the load was increased until the specimen breaks.
3. The maximum load resisted by the specimen was noted down.
4. Compressive strength was determined by dividing the maximum load resisted by specimen to that of the area of the specimen.

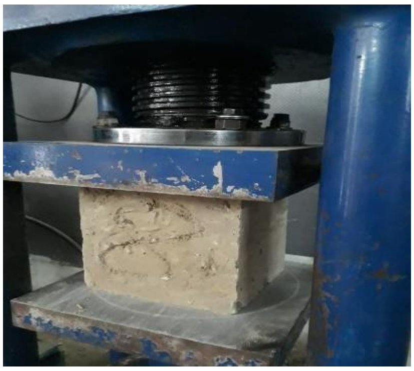

Figure 5Testing of cube in the compression testing machine

Flexural strength test

Flexural strength test is carried out to determine the flexural strength of specimen. For this test beam of size 100mm×100mm×500mm was casted and cured in direct sunlight for 3, 7 and 28 days. All these specimens were tested in the beam testing machine as shown in Figure 6.

Procedure for flexural strength test

1. Primarily the beam specimens were placed on the rollers provided on the bed of the machine.
2. Once the beam specimen was placed properly the load was applied gradually until the specimen fails.
3. The maximum load resisted by the specimen was noted down.
4. Theflexuralstrengthwascalculatedbydividingtheloadresistedbythespecimen

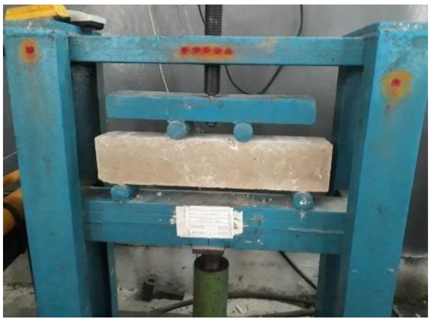

Figure 6 Testing of beam in the beam testing machine

RESULTS AND DISCUSSION

Here, the results obtained from the experimental study of geopolymer concrete have been presented. The result of fresh concrete test (slump test) and mechanical properties such as compressive strength and flexural strength test of various geopolymer concrete mixes with variation of molarity of NaOH is shown. The variation of mechanical properties with the variation of molarity of sodium hydroxide and age of curing has been presented in detail.

Workability of geopolymer concrete

In order to study the workability, the slump cone test was carried out on the freshly prepared Geopolymer concrete. Slump for different molarity of NaOH in geopolymer concrete are listed in the below table.

Table 4 Slump for different molarity

Sr.No	Molarity	Slump (in mm)
1	8M	30
2	10M	55
3	12M	70

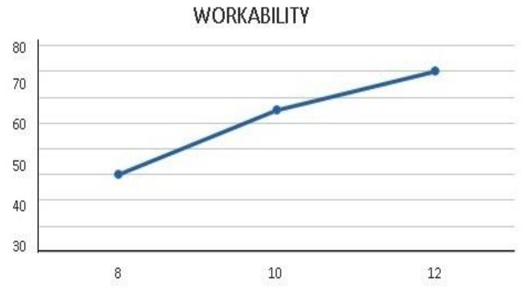

Figure 7 Variation of workability of GPC with increase in the molarity of NaOH

It was observed that work ability of geopolymer concrete decreased as molarity of sodium hydroxide was increased, this is because of the highly alkalinity of mix. As the molarity of NaOH increased the alkalinity of the mix increased, due to high alkalinity, rate of reaction increased i.e. rate of geo-polymerization increased. As rate of reaction increased, setting time of geo polymer mix decreased so it sets very fast. GGBS based geopolymer concrete is very less workable after 10-15 minutes.

Compressive strength of Geopolymer concrete

The cubes specimen of dimensions 150×150×150 mm are prepared and tested to study the effect of variation of molarity of NaOH on compressive strength of geo polymer concrete. The molarity of NaOH used in geopolymer was 8M, 10M, and 12M. All the specimens are cured and then are tested for compressive strength. The compressive strength of specimens for various molarity of NaOH for different curing age is tabulated in Table.5.

It was observed from the above table that the compressive strength of GGBS based geopolymer concrete increases with the increase in molarity of NaOH. It is due to increase in alkalinity of mix, which increase the rate of geo-polymerization. It can also be observed from the above table that compressive strength increases with the age of concrete specimens, although this increase in strength is very gradual. The average compressive strength of all the geopolymer concrete mixes with respect to molarity of NaOH and their testing age are plotted in the below graph

Table 5 Compressive strength for different molarity

Age of specimens in days	Compressive Strength in Mpa		
	8 M	**10 M**	**12 M**
7	40.02	47.91	56.9
14	42.24	49.3	58.5
28	43.96	52.4	60.4

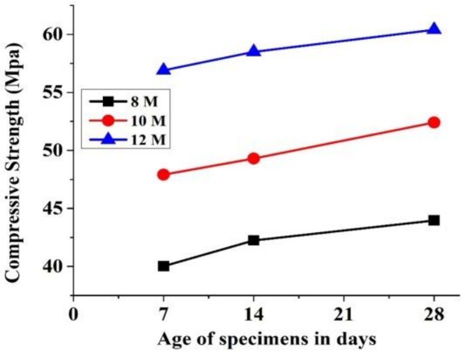

Figure 8 Average compressive strength of all geopolymer concrete

Figure 8 shows that with the age of specimen and molarity of NaOH, the compressive strength increases. Hence the solution with 12M molarity of NaOH, the compressive strength increases to 60.4 MPa.

Flexural strength of Geopolymer concrete

Flexural strength testing of the GPC mixes is conducted to investigate the effect of molarity of NaOH on bending strength of geopolymer concrete. Beam specimens of size 100mm×100mm×500mm are casted and cured in direct sunlight to study the effect of variation of molarity of NaOH on flexural strength of geopolymer concrete. The flexural strength test results showing effect of molarity are tabulated in the below table.

The above table shows that the flexural strength increases with the age of concrete for all the molarities of NaOH just like the compressive strength. The flexural strength of all the Geopolymer concrete mixes with respect to molarity of sodium hydroxide and their testing age are plotted in Fig.9.

Table 6 Flexural strength test for different molarity

Age of specimens in days	Flexural Strength in Mpa		
	8 M	**10 M**	**12 M**
7	0.42	0.53	0.64
14	0.49	0.61	0.72
28	0.56	0.67	0.79

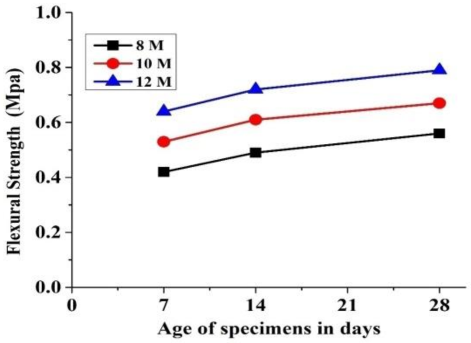

Figure 9 Flexural strength with respect to molarity of all geopolymer concrete mixes

From above result it has been seen that the mechanical properties i.e. compressive strength and flexural strength of GGBS based GPC increase with rise in molarity of alkaline solution. This increment in strength may be because of increase in pH of solution. By this we can see that when molarity of solution has increased, more Na and OH ions are available in solution which reacts with silicon (Si) and aluminum (Al) minerals present in GGBS, So more silicon (Si) and aluminum (Al) are activated by alkaline solution which increased the rate of reaction of geo-polymerization.

CONCLUSION

GGBS based geo polymer is less workable with the increase in the molarity of the NaOH. Geo-polymerization reaction of GGBS based geopolymer concrete is fast at the ambient temperature, hence its starts setting after10 to 15minutes of mixing. Compressive strength of GGBS increases with increase in the molarity of NaOH in the alkaline solution. The GGBS developed compressive strength of about43MPa for 8M, 52.4MPa for 10M and 60.4MPa for 12M after 28 days of direct sunlight curing. In GGBS based geo polymer concrete the time taken to achieve the maximum strength is very fast. At the 7 days of sunlight curing almost maximum strength is achieved, and after 7days the increase in the compressive strength is slower. GGBS based geo polymer concrete develops a flexural strength of 0.56MPa for 8M, 0.67MPa for 10M and 0.79MPa for 12M after 28 days of direct sunlight curing. So the replacement on normal cement concrete by GGBS based Geopolymer concrete is possible, as the GGBS based geo polymer concrete has got the higher compression and flexural strength.

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